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SOUTHWEST FISHERIES SCIENCE CENTER
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THE ABUNDANCE OF CETACEANS IN CALIFORNIA WATERS ESTIMATED FROM SHIP SURVEYS IN SUMMER/FALL 1991

By

Jay Barlow

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Jay Barlow

National Marine Fisheries Service
Southwest Fisheries Science Center
P.O. Box 271
La Jolla, CA. 92038

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Jay Barlow
Southwest Fisheries Science Center
National Marine Fisheries Service
P.O. Box 271, La Jolla, CA 92038

ABSTRACT

A ship survey was conducted in summer/fall 1991 to estimate the abundance of cetaceans in California waters between the coast and approximately 300 nmi (555 km) offshore. Line-transect methods were used with 2 observers searching through 25x binoculars and a third observer searching by unaided eye and 7x binocular. A fourth conditionally-independent observer searched intermittently and was used to estimate the fraction of trackline groups missed by the primary team. Approximately 5,600 nmi (10,360 km) were searched and 556 groups of cetaceans were seen. For estimating abundance, an objective method (Akaike's Information Criterion) was applied to define strata based on sighting conditions. The estimated fraction of trackline groups that were seen varied between 0.65 and 1.0 for different species and group sizes. Abundance estimates (and C.V.s in parentheses) are 250,000 (0.28) short-beaked common dolphins (Delphinus delphis delphis), 11,600 (0.71) long-beaked common dolphins (Delphinus delphis bairdii), 20,700 (0.43) striped dolphins (Stenella coeruleoalba), 13,100 (0.56) Pacific white-sided dolphins (Lagenorhynchus obliquidens), 9,390 (0.55) northern right whale dolphins (Lissodelphis borealis), 82,900 (0.35) Dall's porpoise (Phocoenoides dalli), 1,610 (0.47) bottlenose dolphins (Tursiops truncatus), 9,430 (0.40) Risso's dolphins (Grampus griseus), 431 (1.21) killer whales (Orcinus orca), 725 (0.47) sperm whales (Physeter macrocephalus), 37 (1.00) Baird's beaked whales (Berardius bairdii), 913 (0.59) fin whales (Balaenoptera physalus), 2,200 (0.36) blue whales (Balaenoptera musculus), 609 (0.41) humpback whales (Megaptera novaeangliae), 344 (0.813) pygmy sperm whales (Kogia breviceps), 1,750 (0.86) Cuvier's beaked whales (Ziphius cavirostris), and 569 (1.10) minke whales (Balaenoptera acutorostrata). Estimates are also made for various other species which could only be identified to genus or other higher-level taxa.

INTRODUCTION

The abundance of cetaceans in California coastal waters is poorly known for the majority of species found there. For small cetaceans, quantitative estimates of abundance with statistical confidence limits are only available for common dolphins (Delphinus delphis) (Dohl, Bonnell, and Ford 1986) and for harbor porpoise (Phocoena phocoena) (Barlow 1988). For large cetaceans, such estimates are available for gray whales (Eschrichtius robustus) (Reilly 1984; Buckland 1990), humpback whales (Megaptera novaeangliae) (Calambokidis et al. 1990a; 1992), and blue whales

(Balaenoptera musculus) (Calambokidis et al. 1992). Estimates have been made for some of the other species (Dohl et al. 1980; Dohl et al. 1983), but these estimates are more than 10 year old and most lack information on statistical precision.

Many, and perhaps all, cetaceans in California coastal waters are vulnerable to entanglement and death in gillnet fisheries. A program is now in place to estimate the incidental mortality of cetaceans in the California gillnet fisheries (Lennert et al., in press). It is difficult, however, to assess the impact of gillnet mortality on cetacean populations without knowing cetacean population sizes.

Coordinated ship and aerial surveys were initiated recently to estimate the abundance of all cetacean species in the region of California gillnet fisheries. To evaluate the effect of seasonality on cetacean abundance, surveys were designed to cover both cold-water months (Feb-Apr) and warm-water months (Jul-Nov). A research vessel was used to conduct the ship survey during the warm-water period of 1991; results from this survey are reported here. An aircraft was used to survey during the cold-water periods of both 1991 and 1992; preliminary population estimates from the 1991 survey are reported by Forney and Barlow (in press).

FIELD METHODS

Stratification

A line-transect survey was conducted from July 28 to November 5, 1991 to assess the abundance of cetaceans in California coastal waters using the 53 m National Oceanographic and Atmospheric Administration's (NOAA) vessel McARTHUR. Primary cruise tracks were drawn to uniformly cover the waters from the 10-fathom (18 m) isobath to approximately 300 nmi (555 km) offshore (Fig. 1). This region encompasses the area from the shallowest navigable depth for this survey vessel to the approximate outer boundary of the California Current system. Because, based on a priori experience, cetaceans were expected to be more common in the vicinity of the Channel Islands (Fig. 2) and because logistics required the vessel to navigate around some of the islands to complete primary tracklines, a secondary stratum was created to include circumnavigations of each of the Channel Islands at a distance of approximately 1 nmi (1.85 km) from shore. (Henceforth, these two strata will be referred to as the "main study area" and the "island stratum".)

Primary Observation Team

The basic survey method was that which was developed and used to estimate the abundance of small cetaceans in the eastern tropical Pacific (Holt and Powers 1982; Holt 1987; Holt and Sexton 1989; Wade and Gerrodette 1992). The primary observation team consisted of 3 observers who searched from the flying bridge deck at a viewing height of 10 m above the sea surface. Two teams of 3 observers were rotated every 2 hours to avoid fatigue. The same 6

people worked in these 3 positions for the duration of the cruise. Sighting effort was maintained from dawn to dusk whenever weather conditions allowed, and searching covered the entire region from directly in front of the vessel to 90 degrees left and right and out to the horizon. Two observers on a team searched by looking through 25x pedestal-mounted binoculars on the port and starboard sides of the vessel. The third observer searched by unaided eye and (occasionally) 7x binoculars and also served as data recorder. Data were recorded on a lap-top computer which had direct input from the ship's GPS navigation system. Recorded data included sighting conditions (sea state, cloud cover, sun position, etc.), observer positions, the beginning and end of effort, and information pertaining to sightings.

When a sighting was made, all observers were made aware of the animals' location. The perpendicular distance from the trackline to the center of the group was estimated from the initial bearing and distance. The initial bearing of a cue (a blow, a splash, or a sighting of animals) was measured relative to the direction of the vessel using a calibrated collar on the base of the yoke of the 25x binoculars. The initial distance was typically estimated from a calibrated reticle scale in the oculars of both the 25x and 7x binoculars, or, if a shore horizon was closer than 6 nmi, from comparison to the radar-measured distance to shore. Occasionally, for very close animals seen only by the third observer, sighting distances and angles were estimated "by eye". If a cue turned out to be a cetacean, effort was interrupted and the ship was typically diverted towards the animals in order to obtain estimates of species composition and group size. The vessel was not typically diverted for cetaceans which were greater than 3 nmi (5.55 km) perpendicular distance from the trackline.

Species identification was made collectively by the team, but quantitative estimates of species composition and group size were made independently by each observer. For estimation purposes, a group was defined as a collection of closely associated individuals (typically within several body lengths of each other) which exhibit cohesive behavior. In the field, however, a single distant sighting might prove to be two behaviorally distinct groups upon closer inspection. In such cases, when it was impossible to determine which was the original group sighted, both groups were pooled to estimate group size and species composition. For mixed-species groups, species composition was recorded as an observer's estimate of the percentage of each species present in the group. Three estimates of group size were recorded by each observer: a "best" estimate, a "high" or upper estimate of the number present, and a "low" or lower estimate of the number present. Species composition and group size data were written confidentially in personal notebooks and were transcribed at the end of the day into the computer data record by the cruise leader.

Species Identification

Observers attempted to classify all the species present in a group to the lowest possible taxonomic level (one member of each team was a cetacean identification expert with experience on at least 3 prior marine mammal surveys). In the case of common dolphins, observers were asked to classify groups to the level of sub-species (ie. to distinguish between the short-beaked, offshore, or "delphis" form and the long-beaked, Baja neritic, or "bairdii" form (Heyning and Perrin 1991)). Several higher taxonomic groups were used in cases when species or sub-species identification was not possible. These higher groups were: the genus Mesoplodon (including mesoplodont beaked whales); unidentified sei or Bryde's whale; unidentified beaked whale (including members of the genera Mesoplodon and Ziphius); unidentified large whale (including members of the species group "large whale" in Table 1 plus the genera Eschrichtius and Eubalaena); unidentified baleen whale (including members of the genera Balaenoptera, Megaptera, Eschrichtius, and Eubalaena); unidentified small whale (including members of the species groups "small whale" and "large delphinid" in Table 1); unidentified delphinoid (including members of the species groups "small delphinid", "large delphinid", and "cryptic species" in Table 1); and unidentified cetacean (which could include any of the species listed above or in Table 1). The number of sightings identified to these higher taxonomic levels is relatively small (Table 1) and will not be included in the abundance estimates for individual species.

Independent Observer

In addition to the primary observation team, a fourth observer was on duty approximately 82% of the time and looked for cetaceans that were missed by the primary team. This independent observer searched from the flying bridge using 7x binoculars and unaided eyes and did not reveal the presence of cetaceans until after they were clearly missed by the primary observation team (ie., after they had passed abeam of the vessel or were bow-riding). Nine different people served as independent observers during the survey, and all worked irregular schedules which overlapped with both primary teams. To avoid fatigue, independent observers did not work more than 2 consecutive hours. When a sighting was made by the independent observer, that person maintained their normal behavior, so as to avoid drawing the attention of the primary observer team. Initial bearing and distance were estimated "by eye" or with the aid of reticles in the ocular of 7x binoculars and a protractor mounted in front of the observation station. After a group was clearly missed by the primary team, the independent observer announced the presence of the animals to the data recorder and gave the initial bearing and distance. When possible, the vessel was diverted towards the group, and species composition and group size were estimated by the primary observation team.

ANALYTICAL METHODS

Cetacean abundance was estimated from survey data using line transect methods (Buckland et al., in press). The basic equation for estimating abundance, N, for grouped animals using line transect is given by

$$N = \frac{A\ n\ S\ f(0)}{2\ L\ g(0)} \qquad (1),$$

where
- A = size of the study area,
- n = number of sightings,
- S = mean group size,
- f(0) = sighting probability density at zero perpendicular distance,
- L = length of transect line completed, and
- g(0) = probability of seeing a group directly on the trackline.

Ideally, in a simple case, S, f(0), and g(0) would be estimated separately for each species. However, the presence of mixed-species groups and small samples sizes required pooling for the estimation of f(0) and g(0). The parameter f(0) was estimated using the hazard rate model (Buckland 1985). This model was fit by maximum likelihood using ungrouped perpendicular distances. Perpendicular distances were estimated from bearing and radial distance estimates made by observers. Because there was a tendency for observers to round bearing estimates to the nearest 5-degrees, angle measurements were smeared (Butterworth 1982) by adding a random angle distributed uniformly between -5 and +5 degrees.

Pooling and Stratification for Estimating f(0)

Pooled f(0)s were estimated for 5 species groups: "small delphinids", "large delphinids", "small whales", "large whales", and "cryptic species". The 5 species groups were defined to include all of the species seen on the survey (Table 1) and were based on patterns of species co-occurrence in groups and similarities in the physical and behavioral attributes that affect sightability from a ship. As an example, bottlenose dolphins (Tursiops truncatus) were never seen in a single-species group but were seen with Risso's dolphins (Grampus griseus) 14 times, with striped dolphins (Stenella coeruleoalba) 1 time, and with sperm whales (Physeter macrocephalus) 3 times. Bottlenose dolphins were pooled together with Risso's dolphins because they were seen most frequently with that species and because their sighting characteristics are more similar to Risso's dolphins (medium body size, prominent dorsal fin, occasional low puffy blow, small to medium group size) than to the other two species they were seen with. Because killer whales (Orcinus orca) were never seen with other species but share the same sighting characteristics, these were also included in the species group "large delphinids". The sighting characteristics of the other 4 groups are: "small

delphinids" which are obviously of small body size and are found in medium to large groups; "small whales" which are of medium body size, typically show no blow, often surface inconspicuously, and are typically found in small groups; "large whales" which are obviously of large body size, almost always show a conspicuous blow, and are found in small to medium groups; and "cryptic species" which are small, show no blow, typically surface inconspicuously, and are found in small groups. Unidentified baleen whales and unidentified large whales were included in the species group "large whale" because for 94% of these sightings a blow was described as the primary sighting cue. Unidentified cetaceans and unidentified small whales had mean group sizes of less than 2 and were included in the species group "small whale". The assignment of other higher taxa to species groups was based on similar criteria and is given in Table 1.

Although pooling of species was necessary for estimating f(0), it is certainly not true that all groups of animals within a species group are equally likely to be seen at a given distance from the trackline. Although line-transect models typically show "pooling robustness" (Burnham et al. 1980), excessive pooling (especially across groups of various sizes) can result in bias (Drummer and McDonald 1987; Buckland et al., in press). Within each species group, I therefore apply a strategy recommended by Buckland et al. (in press) of stratifying by factors that are likely to affect sightability. To avoid estimating more parameters than are justified by the data, I chose the most parsimonious stratification model for estimating f(0) by minimizing Akaike's Information Criterion (AIC) (Akaike 1973). AIC is defined as 2 times the number of parameters used to estimate f(0) values minus 2 times the sum of the log-likelihoods of the fitted values of f(0). Stratifications using 3 group size categories [small (1-20), medium (21-100), and large (>100)] and 2 sea state categories [calm (Beaufort sea state of 2 or less) and rough (Beaufort 3 or greater)] were investigated. Using the hazard rate model, I computed AIC for group size stratification, for sea state stratification, and for all possible cross-stratifications (e.g. calm X rough/small X rough/medium X rough/large). A slightly different stratification scheme was used for "cryptic species" and "large whales". The "cryptic species" never occurred in mixed-species groups, and sample size was sufficient to estimate f(0) separately for harbor porpoise and Dall's porpoise (Phocoenoides dalli). For these porpoise species, I estimated AIC for the stratifications of species (Dall's and harbor porpoise separately), sea state, and species X sea state. For "large whales" I used group size strata of small (1-3)and large (>4). The model which gave the lowest AIC value for a given species group was used to estimate abundance for all species in that group.

When stratifying by group size, estimates of density in the various strata are added together to give an overall density. The equation for estimating abundance of each species is therefore

given by

$$N_k = \sum_{i=1}^{2} A_i \sum_{j=1}^{3} \frac{n_{i,j,k}\ S_{i,j,k}\ f_{j,k}(0)}{2\ L_i\ g_{j,k}(0)} \qquad (2),$$

where

A_i = size of area stratum i,
$n_{i,j,k}$ = number of sightings in area i of species k in group size stratum j,
$S_{i,j,k}$ = mean group size in area i of species k in group size stratum j,
$f_{j,k}(0)$ = sighting probability density at zero perpendicular distance for group size stratum j of the species group to which species k belongs,
L_i = length of transect line completed in area i, and
$g_{j,k}(0)$ = probability of detecting a group directly on the trackline for group size stratum j of the species group to which species k belongs.

Perpendicular Distance Truncation

Sightings of distant groups add little to the estimation of trackline density and can introduce bias. Fitting the tails of a distribution is often at the expense of obtaining a good overall fit. Therefore, Buckland et al. (in press) recommend generous pruning of distant sightings by truncating with respect to perpendicular distance. As a general rule, they recommend truncating to eliminate the 5-10% of sightings that are farthest from the trackline.

In the current study, groups of cetaceans were typically not pursued for species identification and group size estimation if they were further than 3.0 nmi (5.55 km) from the trackline. In the island stratum, perpendicular distances were truncated at approximately 1.0 nmi (1.85 km) on one side of the vessel by the presence of an island. Therefore, by survey design, perpendicular distances must be truncated at no more than 3.0 nmi for the main study area and no more than 1.0 nmi for the island stratum.

For the main study area, a truncation distance of 2.0 nmi (3.7 km) was used for "small delphinids", "cryptic species", "large delphinids", and "small whales", which eliminated 8.8%, 2.4%, 4.6%, 12.8%, and 11.1% of all groups (respectively). A truncation distance 3.0 nmi (5.55 km) was used for "large whales", which eliminated 10.9% of groups. For the island stratum, a truncation distance of 1.0 nmi (1.85 km) was used for all species groups.

Group Size Estimation

The estimation of group size for cetaceans is difficult and can lead to bias in the estimation of abundance. To avoid bias,

correction factors can be developed for individual observers. Four of the 6 primary observers on the present survey had been previously calibrated using aerial photographic estimates to represent "true" group size (Gerrodette and Perrin 1991). The "best" estimates of 2 of these 4 were found to accurately indicate group size and did not require any correction factors. The other 2 required correction factors which were based on a linear combination of their "best", "high", and "low" estimates, and, for one, correction factors varied significantly from one year to the next. A helicopter was not available to make aerial photographic estimates of group size on the present survey, so correction factors for individual observers were estimated indirectly by comparison to the 2 observers who, in the previous study, did not require correction.

Linear regression was used to compare one observer's estimates of group size to another's for the subset of groups that were estimated by both. Group sizes were log-transformed to normalize variances (Gerrodette and Perrin 1991). For the two observers who did not require a correction factor in the previous study, the slope of the regression was 1.009 (s.e.=0.017), indicating that, relative to each other, they were still estimating group size consistently. Correction factors for the other 4 observers were based on the slope and intercept of the regression of their "best" estimates against the mean of "best" estimates of the two who did not need calibration.

The group size for each species in a group was estimated as the average of all observers' corrected estimates of the size of the group times the average of all observers' estimates of the percentage of that species present (if in a mixed-species group).

Probability of Detecting Trackline Groups

Estimating the probability that a group on the transect line will be seen, g(0), is fraught with difficulties (see Buckland et al. (in press) for a review of previous attempts). In the context of bias from missed groups of marine mammals, it is useful to think in terms of the dichotomy proposed by Marsh and Sinclair (1989): bias can result from groups that were available to be seen but were not (perception bias) and from groups that were not available to be seen either because they did not surface or because they surfaced behind a swell (availability bias). I will make a minimum estimate of perception bias based on data collected by the conditionally-independent observer using the approach given in the Appendix. Because the sample of sightings made by independent observers is small (only 37 cetacean groups), $f_2(0)$ in Eq. 7 was estimated for all cetaceans pooled without stratification by group size or sea state. Perpendicular distance data were fit with the Hazard rate model to estimate $f_2(0)$. [Groups are only available to the independent observer if they were missed by the other observers, therefore the distribution of perpendicular distance is not necessarily monotonically decreasing. In this case, however, it is

clearly monotonic, and a more general model is not likely to have performed better than the Hazard rate model.] In estimating the coefficient of variation of $g_1(0)$ from Eq. 8, I used the analytical variances of $f_1(0)$ and $f_2(0)$ from the maximum likelihood fit using the information matrix method and I estimated the variances of n_1 and n_2 by assuming a Poisson distribution. Consideration of availability bias is deferred to the Discussion.

Coefficients of Variation and Confidence Intervals

Coefficients of variation (C.V.) and confidence intervals (C.I.) of the abundance estimates are based on the bootstrap method (Efron 1982; Buckland et al., in press). Sample size in the island stratum was too small; therefore, C.V.s and C.I.s are based on pooled geographic strata using the truncation distance of the main study area. The sightings associated with consecutive segments of search effort were combined to form a set of m subsamples of 75 nmi (139 km) of search effort. Preliminary research showed that subsample lengths of 12.5 to 100 nmi (23 to 185 km) gave comparable estimates of C.V., but that subsamples of 175 and 250 nmi (323 and 462 km) gave higher estimates, perhaps because they included geographic variability in addition to sampling variability. The value of 75 nmi (139 km) was chosen because it approximately equals the average length of transect completed per successful survey day (73.7 nmi/day, excluding days lost completely due to weather), following the guideline suggested by Buckland et al. (in press). I drew m subsamples randomly with replacement from this set of effort segments, and a pseudo-population size was estimated using the same group size/sea state stratifications as were used for the actual abundance estimates. For each bootstrap sample, the probability of detecting trackline groups, g(0), was estimated as a random number between 0 and 1 drawn from a binomial probability distribution with a mean and coefficient of variation equal to the estimated values. This process was repeated 1000 times, and the C.V. of the estimated population size was calculated as the standard error of the 1000 pseudo-population sizes divided by the estimated population size. Bootstrap 95% confidence intervals on the population estimates were based on the 25th and 976th ranked estimates from the bootstrap samples. Log-normal 95% confidence intervals were based on the method given by Buckland et al. (in press) using the bootstrap estimate of C.V.

RESULTS

During the survey approximately 5,600 nmi (10,360 km) of searching effort were completed, and 556 cetacean groups were seen while on effort. During the survey, 18 cetacean species were identified (plus at least 1 species which could only be identified to genus). The locations of sightings for the most common cetacean species are given in Figures 3 through 6. The numbers of on-effort groups seen for each species and species group are given in Table 1. The lengths of transect completed are stratified by sea state and geographic strata in Table 2. Due to logistic constraints,

circumnavigations were not completed for Santa Catalina, San Nicolas, or Santa Barbara Islands in the Channel Island stratum, and for purposes of analysis, the waters around these islands were included in the main study area. Consequently, the main study area (Fig. 1) and island stratum (Fig. 2) contain 237,434 sq. nmi. (812,618 sq. km) and 668 sq. nmi. (2,286 sq. km), respectively. More detailed data summaries for this survey are presented by Hill and Barlow (1992), including the positions and school sizes of all on- and off-effort sightings (including pinnipeds), maps showing the distribution of sightings for each species, distributions of perpendicular distances for each species, patterns of association in mixed-species groups, summaries of searching effort completed under various conditions, and sighting rates of individual observers.

Stratification for Estimating f(0)

Using AIC, different stratifications were chosen for the different species groups. For "small delphinids", "large delphinids", and "large whales", f(0) estimates are stratified by group size. Before stratification, significant negative correlations were found between the logarithm of group size and estimated values of g(x) (Buckland et al., in press) for each of these species groups , but these correlations disappeared after stratifying by group size. For "small whales" and "cryptic species", the correlations between log-group size and g(x) were not significant, and the lowest AIC value was obtained by stratified by sea state. For harbor porpoise and Dall's porpoise there was no improvement by stratifying by species. The same stratifications were used to estimate f(0) for the island stratum. Estimates of f(0) for each species group and strata are given in Table 3 for the main study area and in Table 4 for the island stratum. The shapes of the probability density functions are given in Figure 7. Because the effective strip widths (1/f(0)) were so narrow for "cryptic species" and "small whales" in rough sea states, the potential for bias is very high. Only the calm sea state stratum was used for estimating the abundance of these species. [Despite the smaller sample size, the overall C.V.s were reduced by eliminating rough sea states.]

Group Size Estimation

Correction factors for group size estimation for 4 of the observers were based on the regression of their "best" estimates against the mean "best" estimates of the two observers who were previously found not to require correction factors. The slopes (and intercepts) of these $\log_{10}$-transformed regressions were 0.922 (0.03), 1.022 (-0.03), 0.886 (0.07), and 0.777 (0.11). Three of these observers appear to have underestimated group size, in some cases by a large amount (a group of 500 would have been, on average, estimated as 328, 534, 283, and 152 by the 4 observers, respectively). Group sizes used in subsequent abundance estimates will include correction factors for these 4 observers.

Probability of Detecting Trackline Groups

Independent observers searched a total of 4,570 nmi (8,454 km) or approximately 82% of the total distance searched. Approximately 8% of groups were detected only by the independent observer; however, these groups accounted for only 0.7% of the individuals that were detected. All groups that were detected only by the independent observer were groups of less than 20 individuals. Of all groups less than 20 that were seen while the independent observer was on duty, 347 were seen by the primary observers, and 40 were seen by the independent observer. Estimates of g(0) are given in Tables 3 and 4 for each of the species groups and stratifications that were used for abundance estimation.

Abundance Estimation

Estimates of abundance for each species and higher taxa are given in Table 5, along with estimates of density for each of the sub-strata. Common dolphins were the most abundant cetacean by a large margin. Of common dolphins, the short-beaked variety was much more abundant than the long-beaked variety. Blue whales were the most abundant species of large whale.

DISCUSSION

Distribution

The distribution of cetaceans seen during this survey is in general agreement with the results of other studies in this area (Dohl et al. 1980, 1983, 1986; Leatherwood et al. 1982; Smith et al. 1986; Barlow 1988; Forney and Barlow, in press). For general descriptions of patterns of abundance, the study area can be divided into 3 regions: the waters south of Point Conception (southern California), the waters north of Point Arena (northern California), and the water in between (central California). Common dolphins, bottlenose dolphins, Risso's dolphins, and fin whales were primarily seen in southern California from the coast out to 300 nmi and in central California between 100 and 300 nmi from shore. Pacific white-sided dolphins, northern right whale dolphins, and Dall's porpoise were seen primarily in central and northern California from the coast out to approximately 100 nmi, but Dall's porpoise were also common between 100 and 300 nmi from shore in northern California, and northern right whale dolphins were common in southern California approximately 150 nmi from the coast. Harbor porpoise were seen very close to the coast in central and northern California. Humpback whales were seen primarily in central California between the coast and 50 nmi offshore. Two off-effort sightings were made of single gray whales close to the coast in central and northern California.

There were, however, some surprises in the distribution of species. Striped dolphins occurred rather commonly in mixed groups with common dolphins in southern and central California between 100 and 300 nmi from shore. Although striped dolphins are known to occur in this area (Leatherwood et al. 1982), their frequency of

occurrence was much greater than expected. Blue whales were seen primarily in southern California between the coast and 200 nmi offshore. In previous years, this species was seen commonly in central California between the coast and 50 nmi offshore (Calambokidis et al. 1990b). [However, 1991 may have been an anomalous year for blue whales; few were seen close to shore in central California (Calambokidis, pers. comm.).] Two species were surprising in their absence: short-finned pilot whales (Globicephala macrorhynchus) were previously common in southern California, especially around the Channel Islands in winter, and false killer whales (Pseudorca crassidens) are occasionally seen in southern California waters (Leatherwood et al. 1982). [Note: one group of pilot whales was seen and photographed by independent researchers in the study area between San Francisco and Monterey on Nov 2, 1991 (P. A. Jones, pers. comm.).]

Although the abundance estimates presented in this paper are for the defined study area, it should be emphasized that the distribution of all species extend beyond the study area (Leatherwood 1982). The boundaries of the study area are not likely to include closed populations of any species, except perhaps harbor porpoise (Calambokidis and Barlow 1991). There is a continuous distribution of common dolphins, striped dolphins, bottlenose dolphins, short-finned pilot whales, and false killer whales from the study area south into coastal waters of Mexico. There is a continuous distribution of Dall's porpoise and northern right whale dolphins from the study area north along the coast and perhaps continuing across the North Pacific to northern Japan. Pacific white-sided dolphins, Risso's dolphins, and killer whales are found in adjacent waters both north and south of the study area. Both blue whales and humpback whales are known to migrate into California waters from coastal waters of Mexico and Central America to feed in summer. Gray whales migrate through the study area between summer feeding areas in Alaska and breeding/calving/nursery areas in Mexico.

Abundance

Abundance estimates from this study are also in general agreement with previous estimates (Dohl et al. 1980, 1983, 1986; Barlow 1988; Calambokidis et al. 1990a; Forney and Barlow, in press). This is, however, the first cetacean survey in California waters to include the region between 150 and 300 nmi offshore, and direct comparisons with previous studies are difficult. The studies of Dohl et al. (1980, 1983, and 1986) included only the inshore 90-100 nmi of the present study area. Similarly, estimates made by Forney and Barlow (in press) only include the region inshore of 100-150 nmi. The mark-recapture population estimates of blue and humpback whales by Calambokidis et al. (1990a; 1990b) were based on individuals sighted near the coast. Furthermore, the estimates of Dohl et al. (1980; 1983) do not have associated statistical confidence intervals. Hence, accurate comparisons with previous studies can only be made for the more coastal species and

meaningful statistical tests of differences can be made for even fewer species.

The abundance of harbor porpoise estimated for 1984/85 was approximately 9,576 (c.v.= 0.51) (Barlow 1988, his Regions 1-4), which is smaller than the present estimate of 55,739 (c.v.=0.68). However, given the inappropriate design of the present survey for a very coastal species such as harbor porpoise and the given huge confidence intervals of the present estimate for this species, I recommend that the present estimate of harbor porpoise abundance not be cited. More precise estimates of harbor porpoise abundance are forthcoming from analyses of 1988-91 aerial surveys.

Humpback whale abundance in central California was estimated as 338 based on aerial surveys in August-November of 1980-83 (Dohl et al. 1983); however, this estimate does not include a correction factor for submerged whales. The abundance of humpback whales in fall 1991 was estimated by Calambokidis et al. (1992) to range from 551 to 719 (C.V.s = 0.04 to 0.32), depending on the stratification used. These latter estimates are very close to the present estimate of 609 and are well within its 95% confidence interval.

Despite the seasonal difference in the timing and differences in areal coverage, estimates of abundance from the current ship survey and recent aerial surveys (Forney and Barlow, in press) are very close for several species. Similar estimates of abundance were obtained for total common dolphins (264,000 vs. 278,000), northern right whale dolphins (9,390 vs. 13,400), and Risso's dolphins (9,430 vs 10,500) (ship vs. aerial estimates, respectively). More disparate estimates were obtained for Pacific white-sided dolphins (13,100 vs. 46,300), harbor porpoise (55,700 vs. 1,200), Dall's porpoise (82,900 vs 5,800), bottlenose dolphins (1,610 vs. 4,000), sperm whales (725 vs. 56), and total beaked whales (3,490 vs. 505). It may be important to note that all cases in which the ship estimates are substantially larger than the aerial estimates are for species which spend a large fraction of their time diving (harbor porpoise, Dall's porpoise, sperm whales, and beaked whales). Such species could be more easily missed by aerial observers due to availability bias. In the case of Pacific white-sided dolphins, the aerial estimates may be larger because of a seasonal movement of animals out of Oregon and Washington in winter (Green et al. 1992). Although it is tempting to say more about these differences, it is important to note that these differences are statistically significant only for Dall's porpoise (z-test, $p < 0.01$). Clearly this is due to the large coefficients of variation associated with both the ship and aerial estimates, and a lack of statistical power. More meaningful comparisons can be made after analysis of data from the 1992 aerial survey (Forney and Barlow, in press).

For two species, new estimates of abundance appear to be substantially different than previous estimates. For the late

1970s, the summer/fall estimate of common dolphin abundance was 57,270 (C.V. = 0.17) (Dohl et al. 1986). This estimate is outside the 95% confidence intervals of the current estimate of short-beaked common dolphins. Part of this difference is due to the larger study area included in the present study; however, an even larger apparent increase in common dolphins since the late 1970s was seen for the winter/spring estimates (Forney and Barlow, in press). Dohl et al. (1986) noted a marked decrease in common dolphin abundance from summer/fall to winter/spring; whereas, current estimates for these two seasons are remarkably similar. Because estimates for other small cetaceans are similar in the two studies, I conclude that a large increase in common dolphin abundance is likely. This could have resulted as an effect of the 1991/92 El Niño. Although there were no surface temperature manifestations of El Niño in the study area at the time of the survey, it is possible that common dolphins were moving into California waters from further south as a result of El Niño changes there. Since 1980, a decline has been noted in the abundance of the northern stock of common dolphins south of 30°N (Anganuzzi et al., in press), and those authors hypothesize that this could have been caused by a general northward movement of that stock. This interpretation is consistent with the increases noted here, but the magnitude of the decrease in the south (from approximately 500,000 in 1980 to approximately 100,000 in 1991, Anganuzzi et al., in press) is greater than the entire estimated population in California waters. Stratification of the present survey to include only the study area of Dohl et al. and analysis of past Southwest Fisheries Science Center cetacean surveys in California in 1979 and 1980 may help resolve whether there has been a real shift in the distribution, seasonal movements, and abundance of common dolphins in the Southern California Bight.

The abundance of blue whales is also much higher from the current line-transect data than recent estimates made using individual identification/mark recapture techniques. Although some mark-recapture estimates may be biased low because of geographic heterogeneity in habitat use by individual whales (Hammond 1990), this source of bias should have been eliminated in recent estimates which used the whales identified near the coast in 1990 as the marked sample and the whales identified on the current 1991 ship survey as the recapture sample (Calambokidis et al. 1992). However, even these latter estimates (940, C.V. = 0.36) are much lower than the new line-transect estimates (2,198, log-normal lower 95% C.I. = 1,103). My current estimates of blue whale abundance are also greater than line transect estimates (1,415, C.V. = 0.243) made based on ship surveys in the eastern tropical Pacific from 1986-90 (Wade and Gerrodette 1992). The latter study included sightings made along the coast of Baja California (which are likely to be part of the California feeding population) as well as sightings made near the Costa Rica Dome and along the Equator (which are likely to be part of a different population). Additional studies comparing the assumptions of both mark-recapture

and line transect specifically for blue whales might improve population estimates for this species.

Pooling and Stratification

Parameter estimation involves optimizing the tradeoffs between bias and variance. Pooling samples increases sample size and therefore decreases sampling variance; whereas stratification decreases sample size but can help eliminate bias. The pooling of species into species groups for estimating f(0) and g(0) was based on which species co-occurred most frequently in mixed species groups and on subjective impressions about the sightability of animals. Objective grouping of species by use of AIC or similar methods was not feasible because the sample size for most species was so small that there would be no discernable difference regardless of which group they were assigned to. The number of single-species sightings was greater than 30 for only 4 species (short-beaked common dolphins, harbor porpoise, Dall's porpoise, and blue whales) (Hill and Barlow 1992). I believe that my subjective groupings based on biological criteria are much less likely to result in bias than the essentially random grouping that would have resulted from an attempt to apply objective criteria to data which are not sufficient to discriminate between models.

The stratification of species groups that were chosen by objective techniques (AIC) appear to be biologically reasonable. "Small delphinids", "large delphinids" and "large whales" were stratified by group size, which makes an obvious difference in the probability of detecting a distant group of animals. For porpoises and small whales there is far less variability in group size, but species in these groups often surface inconspicuously. Because distant, inconspicuous surfacings are much more likely to be seen in calm conditions, the stratification by sea state appears appropriate. However, methods used here for estimating the fraction of trackline animals seen appears to be biased for high sea states, and abundance estimates for "small whales" and "cryptic species" should only use data collected under calm sea conditions.

The separation of the Channel Island stratum from the main study area appears justified based on the density of the species which are most commonly found near the islands. The densities of both forms of common dolphins, of bottlenose dolphin, and of Risso's dolphins were much higher in the island stratum. The total numbers of individuals in this stratum were, however, small relative to the total abundance of the species, and any improvement in the precision of abundance estimation is likely to have been trivial. Furthermore, the sample size in this stratum was too small to allow estimation of a separate f(0) or separate bootstrap estimates of statistical precision. This <u>a priori</u> stratification should probably be reconsidered in future surveys.

Probability of Detecting Trackline Groups

The probability of detecting a trackline group of animals, g(0), varied between 0.65 and 1.0. The data clearly indicated that small groups are much more likely to be missed than large groups. This is intuitively obvious and justifies stratifying by group size when estimating g(0) values. The fraction of trackline harbor porpoise seen in calm seas has been estimated previously to be 0.78 (using 5 observers on a similar platform in California, Barlow 1988) and 0.70 (using 6 observers in the Gulf of Maine, Palka 1992). The higher value of g(0) estimated here for "cryptic species" using only 3 observers (0.81) may be due to the inclusion of Dall's porpoise which may be easier to see or may simply be an artifact of small sample size. The higher values of g(0) for rough sea states is counter-intuitive and provides additional justification for using only data collected in calm states for estimating the abundance of "cryptic species" and "small whales".

These estimates of the fraction of animals seen include only animals that were available to be seen. Availability bias is likely to be large for species such as beaked whales which have extremely long dive times and harbor porpoise and Dall's porpoise which have shorter dive times but seldom are seen more than 0.5 km from the ship and may therefore remain submerged during the entire time they are within visual range. Correcting for availability bias is more difficult than for perception bias. Attempts that have been made so far have involved detailed modeling of the surfacing behavior of the animal and the searching behavior of the researchers (Doi 1971, 1974; Barlow et al. 1988; Kasamatsu and Joyce 1991; Stern 1992). In addition, there are still problems with estimating perception bias because the methods used here assume that all animals are equally available to be seen if they surface. Heterogeneity in sightability (eg. animals which splash vs. animals that do not) generally will result in an underestimate of the fraction missed. Additional work is needed to obtain complete estimates of the fraction of trackline animals seen for all species.

Previous studies of Dall's porpoise have shown that attraction to the vessel is a greater problem for that species than missing trackline animals (Turnock and Boucher 1990). Turnock and Quinn (1991) estimated a correction factor of 0.2378 (C.V. = 0.3391) to adjust Dall's porpoise abundance estimates for ship surveys (effectively then, $g_0 = 4.2$). That study was based, however, on a design that used only one observer searching with 7x binoculars and unaided eyes. Most of the animals sighted in that study were rapidly approaching the vessel and were exhibiting the characteristic "rooster-tail" splash of a rapidly moving Dall's porpoise (L. Jones, pers. comm.). In the present study, very few Dall's porpoise appeared to be attracted to the vessel. Of those sighted in calm conditions and used for abundance estimation, only 10% (9 of 88) of the Dall's porpoise groups approached the vessel to "ride the bow wave" and 89% (78 of 88) were exhibiting a "slow

roll" surfacing behavior at the time they were first sighted. Because attraction to the vessel was less than in the other studies and because most Dall's porpoise were sighted before showing any apparent reaction to the vessel (perhaps because 25x binoculars were used), the magnitude of bias is certainly less than that measured in these other studies.

Statistical Precision

An attempt was made to account for most sources of sampling error in the bootstrap estimates of confidence intervals and coefficients of variation. However, several sources of variation could not be easily included. The process of selecting a stratification model via minimizing AIC would have been too time consuming to include in the bootstrap procedure; hence, precision estimates are contingent on the chosen model being approximately correct. Variability in estimating mean group size was included implicitly in the Monte Carlo sampling, but it was assumed that the group size estimate for any given group was accurate. All of these factors would tend to result in precision being overestimated. Because sample size was too small for the island stratum and geographic strata were pooled in the bootstrap, the improvement in precision owing to stratification would be lost, and precision might be underestimated by the bootstrap. The latter effect is likely to be small, and overall, coefficients of variation are likely to be too small and confidence intervals are likely estimated to be narrower than they actually are.

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Table 1. Number of groups of cetaceans seen which contained members of the indicated species and species groups. The sum of all species in a group may be greater than the total for that group because the latter contains mixed-species groups.

Species Group Species	No. of Sightings
Small Delpinids	205
short-beaked common dolphin (Delphinus delphis delphis)	132
long-beaked common dolphin (Delphinus delphis bairdii)	13
unclassified common dolphin (Delphinus delphis)	10
striped dolphin (Stenella coeruleoalba)	24
Pacific white-sided dolphin (Lagenorhynchus obliquidens)	12
northern right whale dolphin (Lissodelphis borealis)	16
unidentified delphinoid	24
Cryptic Species	132
harbor porpoise (Phocoena phocoena)	32
Dall's porpoise (Phocoenoides dalli)	97
pygmy sperm whale (Kogia breviceps)	3
Large Delphinids	39
bottlenose dolphin (Tursiops truncatus)	18
Risso's dolphin (Grampus griseus)	31
killer whale (Orcinus orca)	5
Large Whales	129
sperm whale (Physeter macrocephalus)	13
Baird's beaked whale (Berardius bairdii)	1
Bryde's whale (Balaenoptera edeni)	1
Bryde's or sei whale (Balaenoptera edeni/borealis)	2
fin whale (Balaenoptera physalus)	22
blue whale (Balaenoptera musculus)	49
humpback whale (Megaptera novaeangliae)	14
unidentified baleen whale	9
unidentified large whale	22
Small Whales	56
unidentified beaked whale	7
mesoplodont beaked whale (Mesoplodon spp.)	5
Cuvier's beaked whale (Ziphius cavirostris)	14
minke whale (Balaenoptera acutorostrata)	5
unidentified small whale	13
unidentified cetacean	8

Table 2. Length of transects surveyed, L, stratified by geographic strata and sea state categories of calm (Beaufort 0-2) and rough (Beaufort 3-5).

Geographic Strata Sea State Strata	L (nmi.)
Main Study Area	5440.9
Calm Sea States	1286.8
Rough Sea States	4155.0
Island Stratum	166.2
Calm Sea States	13.1
Rough Sea States	153.2

Table 3. Estimated values of f(0) and g(0) for each of the species group stratifications which were chosen on the basis of AIC minimization. Truncation distances for estimating f(0) are 3.0 nmi for large whales and 2.0 nmi for all other species. Sample sizes include the total number of groups seen by the primary team, n, the number of groups seen by the primary team when an independent observer was on duty, n_1, and the number of groups seen by the independent observers but not by the primary team, n_2.

Main Stratum	Number Sightings			Primary		Secondary		Primary	
Sub-strata					C.V.		C.V.		C.V.
	n	n1	n2	f(0)	f(0)	f(0)	f(0)	g(0)	g(0)
Small Delphinids (2.0 nmi Truncation)									
Group size 1-20	71	58	9	2.235	0.231	3.352	0.152	0.767	0.137
Group size 21-100	62	53	0	2.019	0.321	3.352	0.152	1.000	N.A.
Group size 101+	54	46	0	0.560	N.A.	3.352	0.152	1.000	N.A.
Cryptic Species (2.0 nmi Truncation)									
Calm seas	100	78	14	3.176	0.214	3.352	0.152	0.811	0.091
Rough seas	25	14	5	8.786	0.376	3.352	0.152	0.864	0.104
Large Delphinids (2.0 nmi Truncation)									
Group size 1-20	15	13	1	1.469	0.306	3.352	0.152	0.824	0.233
Group size 21+	19	19	0	0.629	N.A.	3.352	0.152	1.000	N.A.
Large Whales (3.0 nmi Truncation)									
Group size 1-3	88	80	3	1.269	0.321	3.343	0.150	0.901	0.075
Group size 4+	26	24	0	0.453	N.A.	3.343	0.150	1.000	N.A.
Small Whales (2.0 nmi Truncation)									
Calm seas	24	20	2	0.948	0.435	3.352	0.152	0.646	0.478
Rough seas	22	21	1	4.392	0.490	3.352	0.152	0.964	0.043

Table 4. Values of f(0) and g(0) used to estimate the abundance in the island stratum for each of the species group stratifications in Table 3. Data include the island strata and main study area with a truncation distance of 1.0 nmi for all groups. Sample sizes include the total number of groups seen by the primary team, n, the number of groups seen by the primary team when an independent observer was on duty, n_1, and the number of groups seen by the independent observers but not by the primary team, n_2.

tum / ub-strata	Number Sightings			Primary		Secondary		Primary	
	n	n1	n2	f(0)	C.V. f(0)	f(0)	C.V. f(0)	g(0)	C.V. g(0)
hinids (1.0 nmi Truncation)									
roup size 1-20	61	49	9	2.756	0.283	3.411	0.164	0.773	0.144
roup size 21-100	47	41	0	2.794	0.347	3.411	0.164	1.000	N.A.
roup size 101+	31	27	0	1.000	N.A.	3.411	0.164	1.000	N.A.
ecies (1.0 nmi Truncation)									
alm seas	86	67	14	3.715	0.220	3.411	0.164	0.808	0.095
ough seas	25	14	7	12.669	0.607	3.411	0.164	0.865	0.121
hinids (1.0 nmi Truncation)									
roup size 1-20	14	12	1	1.845	0.563	3.411	0.164	0.846	0.218
roup size 21+	12	12	0	1.093	N.A.	3.411	0.164	1.000	N.A.
les (1.0 nmi Truncation)									
roup size 1-3	53	48	3	3.152	0.375	3.411	0.164	0.932	0.052
roup size 4+	11	10	0	1.000	N.A.	3.411	0.000	1.000	N.A.
es (1.0 nmi Truncation)									
alm seas	14	13	2	1.667	0.233	3.411	0.164	0.685	0.373
ough seas	21	20	1	4.545	0.617	3.411	0.164	0.962	0.047

Table 5. Number of groups seen, mean group size, density of individuals, abundance estimates, 95% confidence intervals on those estimates, and coefficients of variation for each species and higher taxa that were identified. Density estimates are based on lengths of transect given in Table 2 and estimates of f(0) and g(0) given in Tables 3 and 4. Mean group size includes only the indicated species and can therefore be less than the minimum of the group size category (which is defined based on the total number of all species present).

Species Area Strata Sub-strata	Numbe Groups n	Mean Size of Groups S	Animal Density /sq nmi	Pop. Size N	C.V.	Bootstrap Lower 95% C.I.	Bootstrap Upper 95% C.I.	Log-Normal Lower 95% C.I.	Log-Normal Upper 95% C.I.
short-beaked common dolphin				249,712	0.275	143,501	409,416	147,099	423,908
Main Study Area			1.0432	247,697					
Group size 1-20	25	11.0	0.0736						
Group size 21-100	52	44.7	0.4314						
Group size 101+	38	275.1	0.5382						
Island Stratum			3.0173	2,016					
Group size 1-20	1	15.1	0.1618						
Group size 21-100	2	76.3	1.2819						
Group size 101+	3	174.4	1.5736						
long-beaked common dolphin				11,599	0.706	0	33,677	3,335	40,342
Main Study Area			0.0420	9,975					
Group size 1-20	1	11.8	0.0032						
Group size 21-100	0	0.0	0.0000						
Group size 101+	3	251.4	0.0388						
Island Stratum			2.4319	1,624					
Group size 1-20	2	12.2	0.2612						
Group size 21-100	0	0.0	0.0000						
Group size 101+	3	240.5	2.1707						
common dolphin (unclassified)				2,859	0.664	338	6,392	875	9,343
Main Study Area			0.0115	2,741					
Group size 1-20	6	5.4	0.0087						
Group size 21-100	1	15.1	0.0028						
Group size 101+	0	0.0	0.0000						
Island Stratum			0.1766	118					
Group size 1-20	1	16.5	0.1766						
Group size 21-100	0	0.0	0.0000						
Group size 101+	0	0.0	0.0000						
striped dolphin				20,715	0.432	7,275	43,301	9,213	46,576
Main Study Area			0.0872	20,715					
Group size 1-20	2	7.7	0.0041						
Group size 21-100	5	29.3	0.0272						
Group size 101+	14	77.6	0.0559						
Island Stratum			0.0000	0					
Group size 1-20	0	0.0	0.0000						
Group size 21-100	0	0.0	0.0000						
Group size 101+	0	0.0	0.0000						
Pacific white-sided dolphin				13,060	0.557	2,168	27,351	4,718	36,153
Main Study Area			0.0550	13,060					
Group size 1-20	7	11.5	0.0215						
Group size 21-100	3	46.2	0.0257						
Group size 101+	2	75.4	0.0078						
Island Stratum			0.0000	0					
Group size 1-20	0	0.0	0.0000						
Group size 21-100	0	0.0	0.0000						

Table 5. (continued).

ecies Area Strata Sub-strata	Numbe Groups n	Mean Size of Groups S	Animal Density /sq nmi	Pop. Size N	C.V.	Bootstrap Lower 95% C.I.	Bootstrap Upper 95% C.I.	Log-Normal Lower 95% C.I.	Log-Normal Upper 95% C.I.
rthern right whale dolphin				9,390	0.547	2,139	20,040	3,446	25,583
Main Study Area			0.0395	9,390					
Group size 1-20	10	9.9	0.0265						
Group size 21-100	3	9.4	0.0052						
Group size 101+	2	75.7	0.0078						
Island Stratum			0.0000	0					
Group size 1-20	0	0.0	0.0000						
Group size 21-100	0	0.0	0.0000						
Group size 101+	0	0.0	0.0000						
dentified delphinoid				3,470	0.507	1,122	6,683	1,360	8,855
Main Study Area			0.0146	3,470					
Group size 1-20	17	3.2	0.0146						
Group size 21-100	0	0.0	0.0000						
Group size 101+	0	0.0	0.0000						
Island Stratum			0.0000	0					
Group size 1-20	0	0.0	0.0000						
Group size 21-100	0	0.0	0.0000						
Group size 101+	0	0.0	0.0000						
rbor porpoise (see footnote)				55,739	0.723	0	144,532	15,636	198,703
Main Study Area, Calm seas	31	5.0	0.2348	55,739					
Island Strata, Calm seas	0	0.0	0.0000	0					
ll's porpoise				82,876	0.347	32,777	133,189	42,774	160,576
Main Study Area, Calm seas	69	3.3	0.3490	82,876					
Island Strata, Calm seas	0	0.0	0.0000	0					
gmy sperm whale				344	0.813	0	2,381	85	1,388
Main Study Area, Calm seas	2	1.3	0.0014	344					
Island Strata, Calm seas	0	0.0	0.0000	0					
ttlenose dolphin				1,606	0.472	525	4,009	667	3,870
Main Study Area			0.0067	1,584					
Group size 1-20	4	2.8	0.0018						
Group size 21+	10	8.3	0.0048						
Island Stratum			0.0334	22					
Group size 1-20	0	0.0	0.0000						
Group size 21+	1	10.2	0.0334						
so's dolphin				9,433	0.396	4,827	21,351	4,467	19,921
Main Study Area			0.0395	9,384					
Group size 1-20	12	8.3	0.0162						
Group size 21+	16	25.2	0.0233						
Island Stratum			0.0733	49					
Group size 1-20	0	0.0	0.0000						
Group size 21+	1	22.3	0.0733						
r whale				431	1.207	0	2,115	67	2,759
Main Study Area			0.0018	431					
Group size 1-20	3	3.7	0.0018						
Group size 21+	0	0.0	0.0000						
Island Stratum			0.0000	0					
Group size 1-20	0	0.0	0.0000						
Group size 21+	0	0.0	0.0000						

Table 5. (continued).

Species Area Strata Sub-strata	Numbe Groups n	Mean Size of Groups S	Animal Density /sq nmi	Pop. Size N	C.V.	Bootstrap Lower 95% C.I.	Bootstrap Upper 95% C.I.	Log-Normal Lower 95% C.I.	Log-Normal Upper 95% C.I.
sperm whale				725	0.472	179	1,459	301	1,745
Main Study Area			0.0031	725					
Group size 1-3	4	1.2	0.0006						
Group size 4+	9	6.6	0.0025						
Island Stratum	0	0.0	0.0000	0					
Baird's beaked whale				37	1.004	0	139	7	188
Main Study Area			0.0002	37					
Group size 1-3	0	0.0	0.0000						
Group size 4+	1	3.7	0.0002						
Island Stratum	0	0.0	0.0000	0					
Bryde's whale				60	1.096	0	183	10	340
Main Study Area			0.0003	60					
Group size 1-3	1	1.9	0.0003						
Group size 4+	0	0.0	0.0000						
Island Stratum	0	0.0	0.0000	0					
Bryde's or sei whale				61	1.021	0	154	12	322
Main Study Area			0.0003	61					
Group size 1-3	2	1.0	0.0003						
Group size 4+	0	0.0	0.0000						
Island Stratum	0	0.0	0.0000	0					
fin whale				913	0.591	135	1,968	312	2,672
Main Study Area			0.0038	913					
Group size 1-3	17	1.4	0.0031						
Group size 4+	4	4.7	0.0008						
Island Stratum	0	0.0	0.0000	0					
blue whale				2,198	0.363	829	3,523	1,103	4,380
Main Study Area			0.0093	2,198					
Group size 1-3	36	1.6	0.0075						
Group size 4+	13	3.3	0.0018						
Island Stratum	0	0.0	0.0000	0					
humpback whale				609	0.409	169	1,085	282	1,316
Main Study Area			0.0026	609					
Group size 1-3	7	1.8	0.0016						
Group size 4+	3	7.3	0.0009						
Island Stratum	0	0.0	0.0000	0					
unidentified baleen whale				209	0.647	17	436	66	667
Main Study Area			0.0009	209					
Group size 1-3	5	1.2	0.0008						
Group size 4+	1	2.1	0.0001						
Island Stratum	0	0.0	0.0000	0					
unidentified large whale				618	0.507	127	1,116	242	1,577
Main Study Area			0.0026	618					
Group size 1-3	15	1.3	0.0026						
Group size 4+	0	0.0	0.0000						
Island Stratum	0	0.0	0.0000	0					

able 5. (continued).

trata b-strata	Numbe Groups n	Mean Size of Groups S	Animal Density /sq nmi	Pop. Size N	C.V.	Bootstrap Lower 95% C.I.	Bootstrap Upper 95% C.I.	Log-Normal Lower 95% C.I.	Log-Normal Upper 95% C.I.
d beaked whale				1,430	0.907	168	6,464	313	6,528
tudy Area, Calm seas	3	3.5	0.0060	1,430					
Strata, Calm seas	0	0.0	0.0000	0					
ont beaked whale				271	0.924	0	984	58	1,263
tudy Area, Calm seas	2	1.0	0.0011	271					
Strata, Calm seas	0	0.0	0.0000	0					
eaked whale				1,754	0.864	184	7,228	406	7,582
tudy Area, Calm seas	7	1.9	0.0074	1,754					
Strata, Calm seas	0	0.0	0.0000	0					
ale				569	1.100	0	3,046	99	3,258
tudy Area, Calm seas	4	1.1	0.0024	569					
Strata, Calm seas	0	0.0	0.0000	0					
d small whale				967	0.869	145	3,225	222	4,207
tudy Area, Calm seas	6	1.2	0.0041	967					
Strata, Calm seas	0	0.0	0.0000	0					
d cetacean				670	0.844	0	2,271	159	2,822
tudy Area, Calm seas	3	1.7	0.0028	670					
Strata, Calm seas	0	0.0	0.0000	0					

More precise estimates for harbor porpoise are recently available in Barlow and Forney (1993).

Figure 1. Transect lines (thin solid lines) completed during the survey. The bold polygon indicates the limit of the main study area.

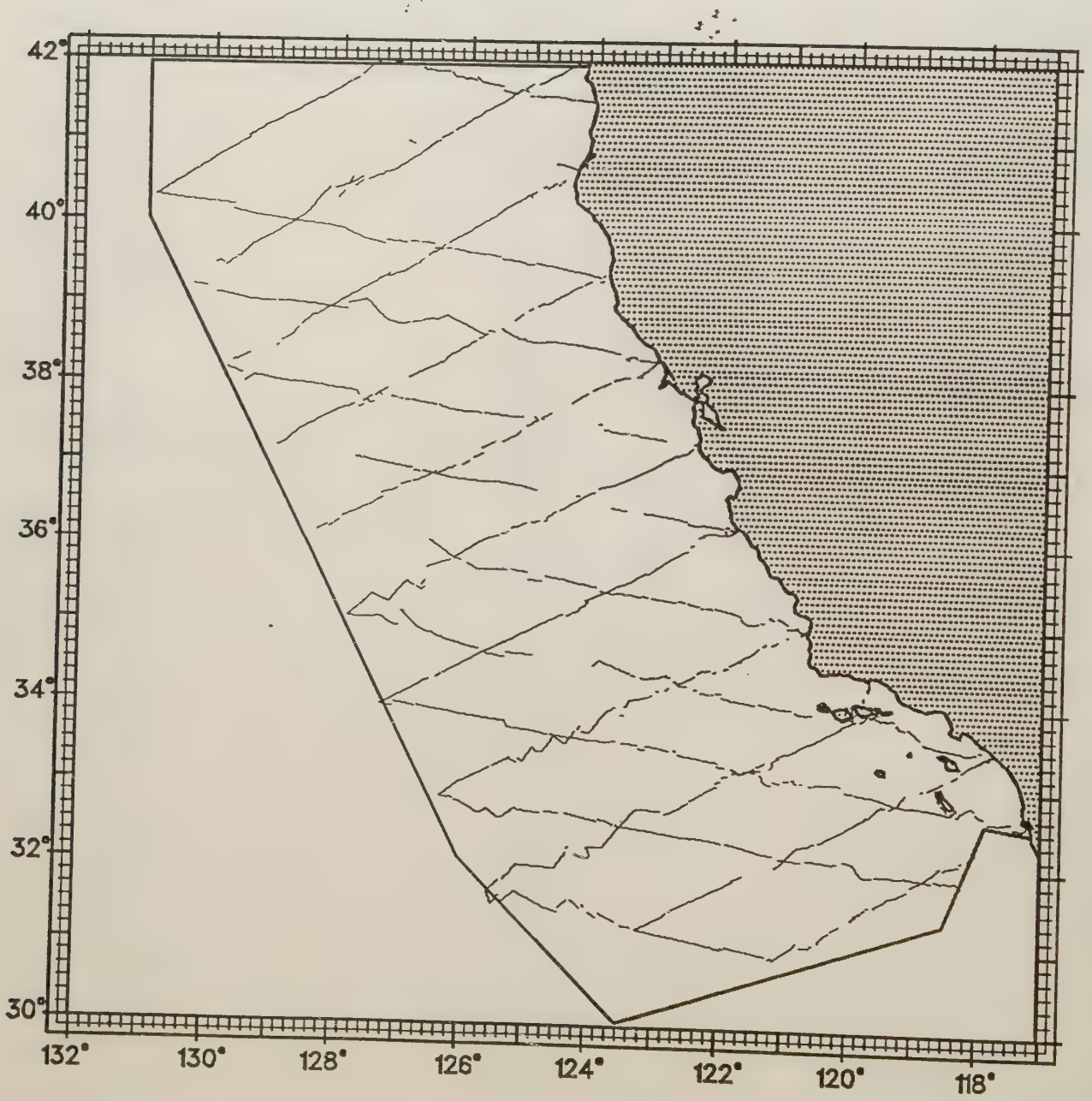


Figure 2. Transect lines (thin solid lines) completed during the survey in the Southern California Bight. The bold polygons indicates the boundaries of the island stratum.

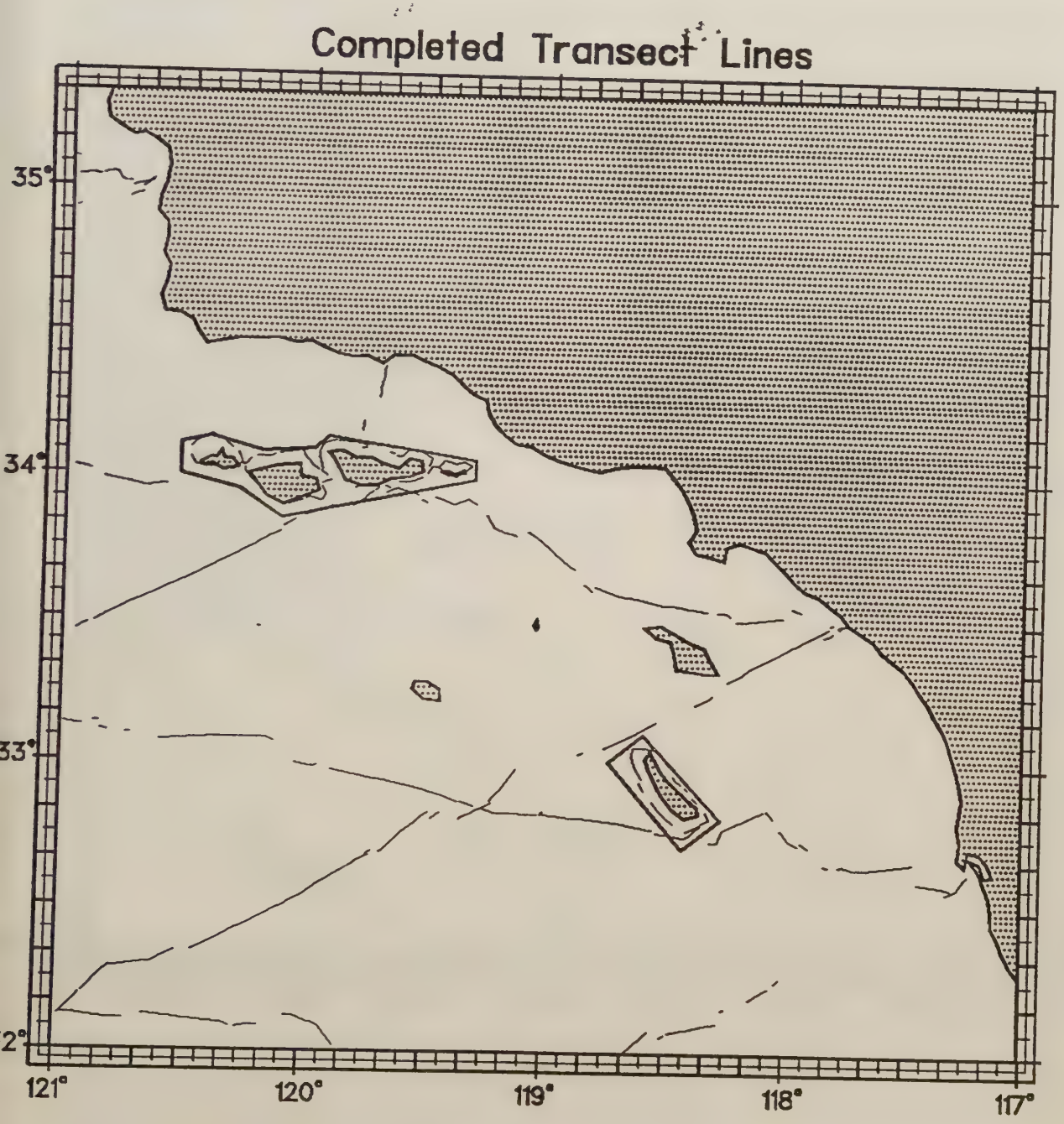
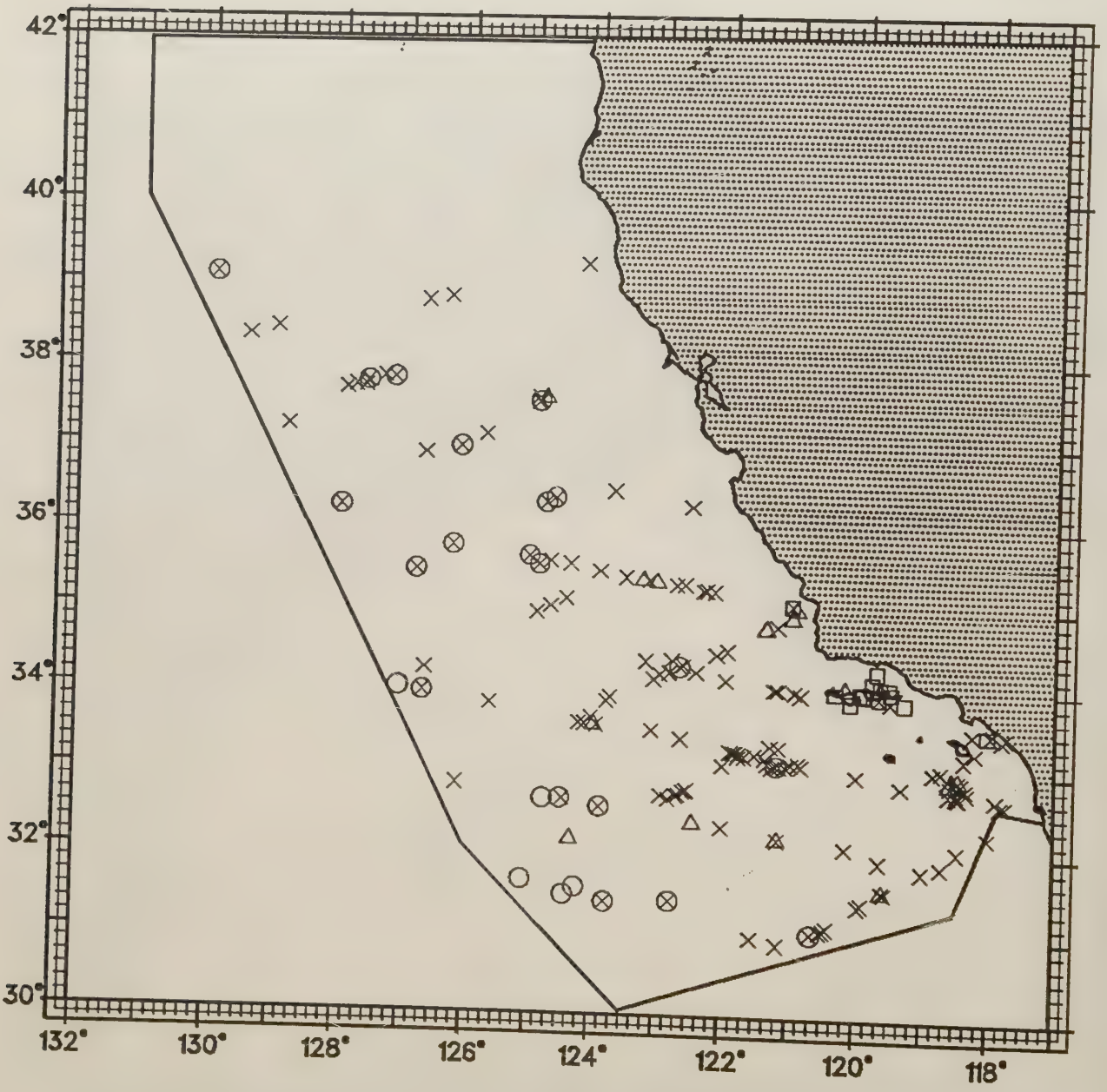


Figure 3. Locations of sightings of short-beaked common dolphins (×), long-beaked common dolphins (□), unidentified common dolphins (△), and striped dolphins (○).



igure 4. Locations of sightings of Dall's porpoise (×), northern ight whale dolphins (△), and Pacific white-sided dolphins (□).

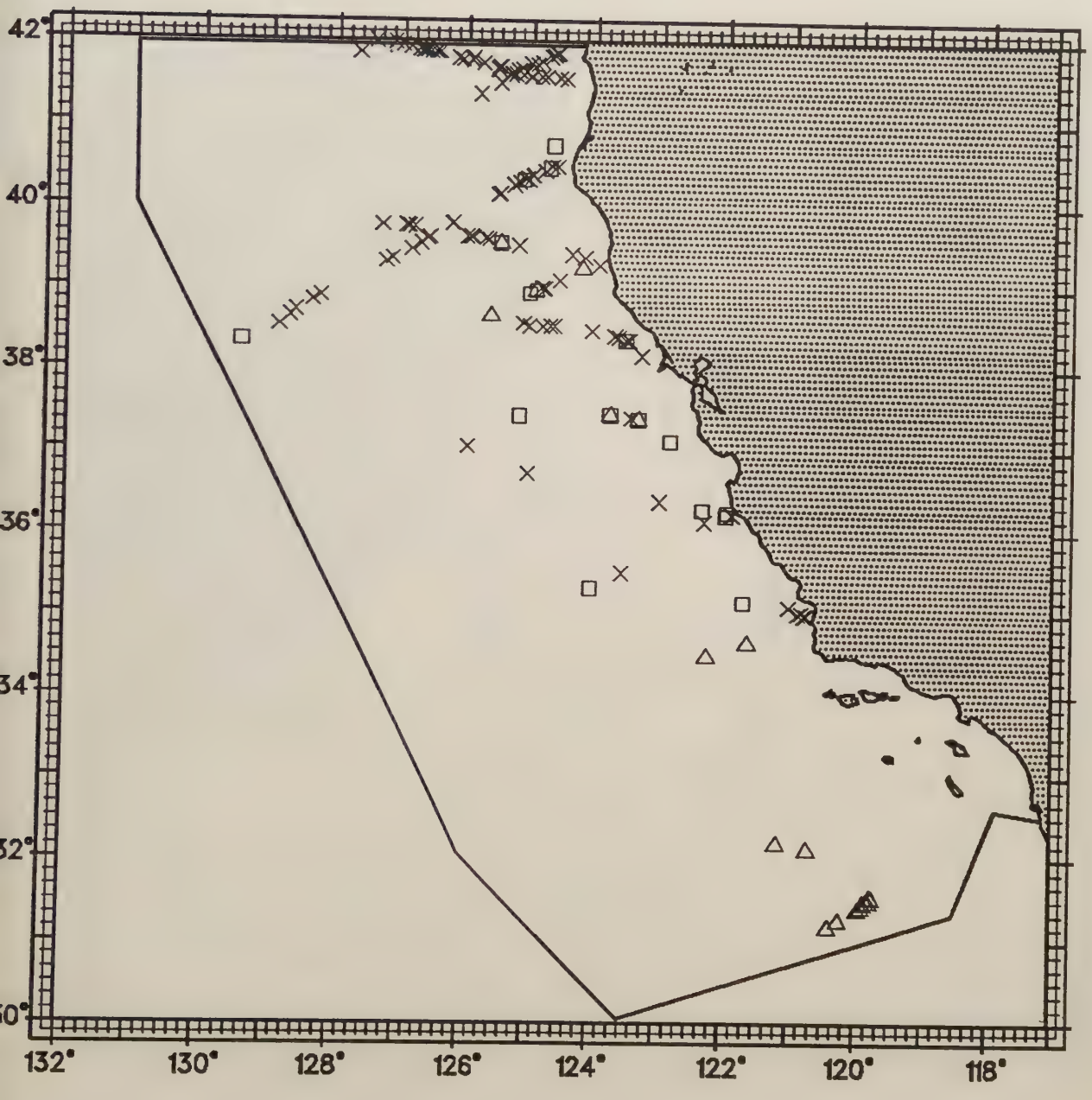


Figure 5. Locations of sightings of killer whales (□), Risso's dolphins (△), and bottlenose dolphins (×).

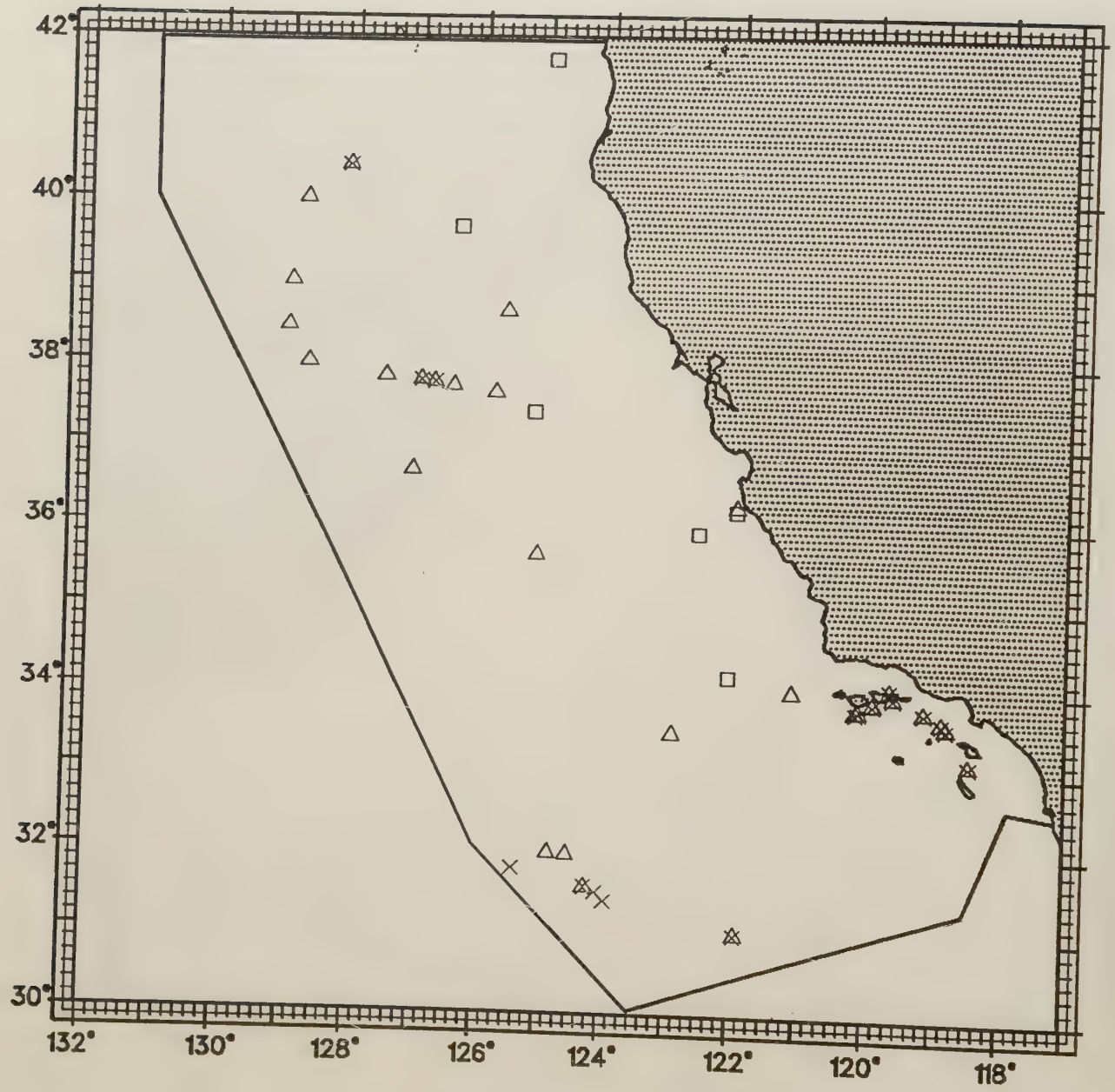


Figure 6. Locations of sightings of fin whales (△), humpback whales (□), blue whales (×), and sperm whales (○).

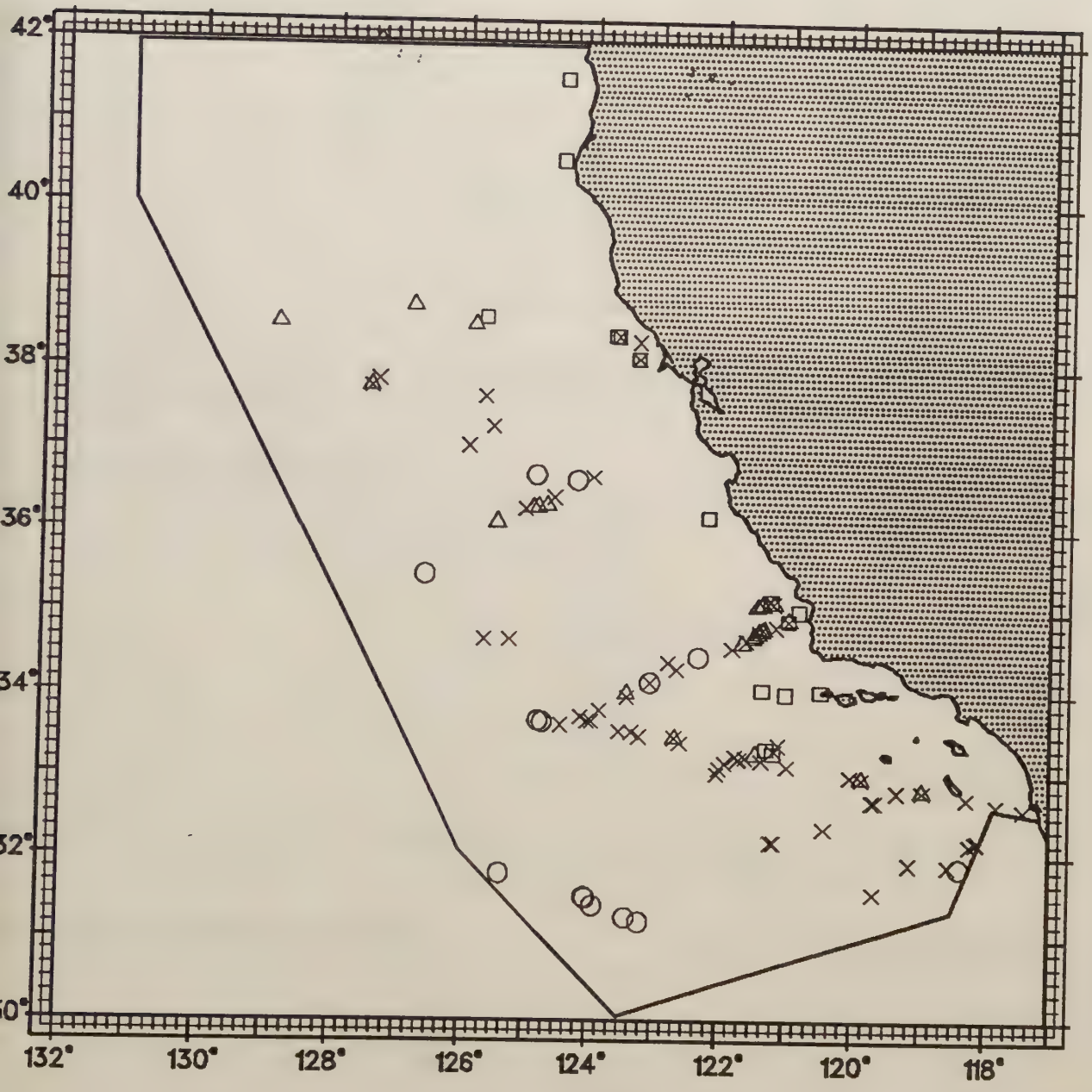
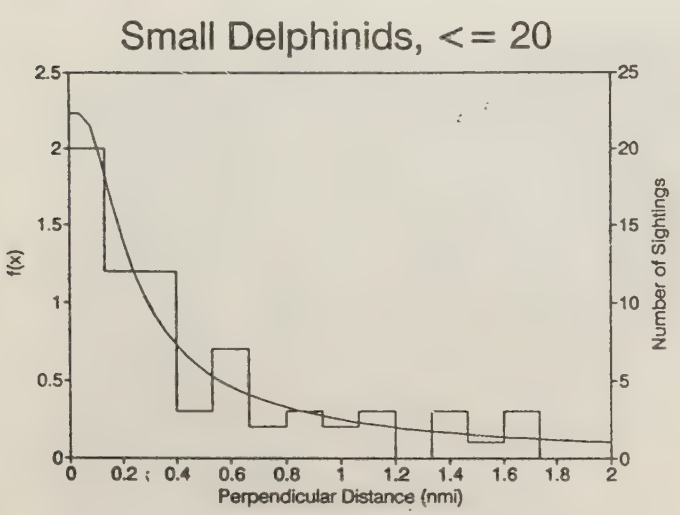
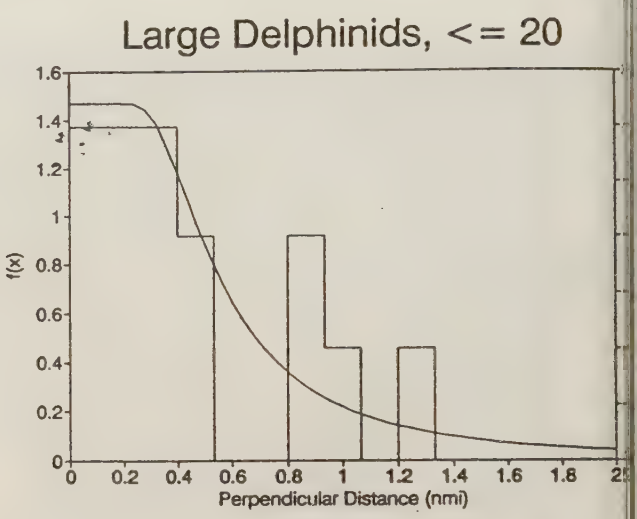
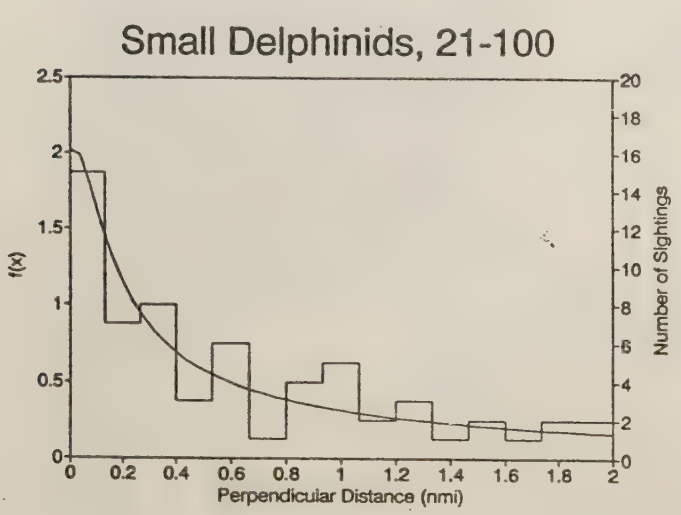
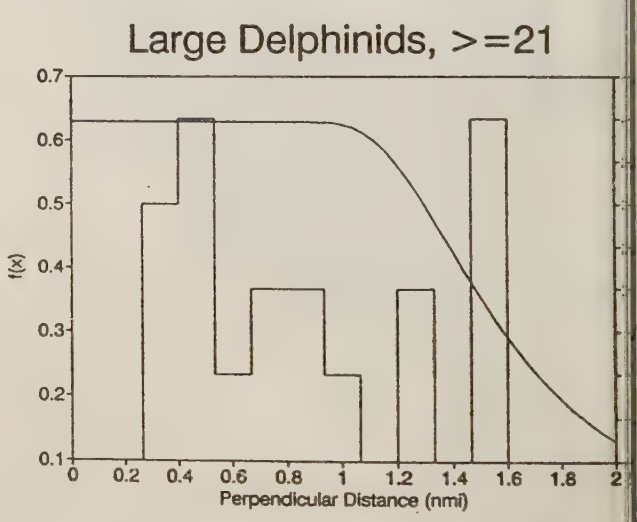


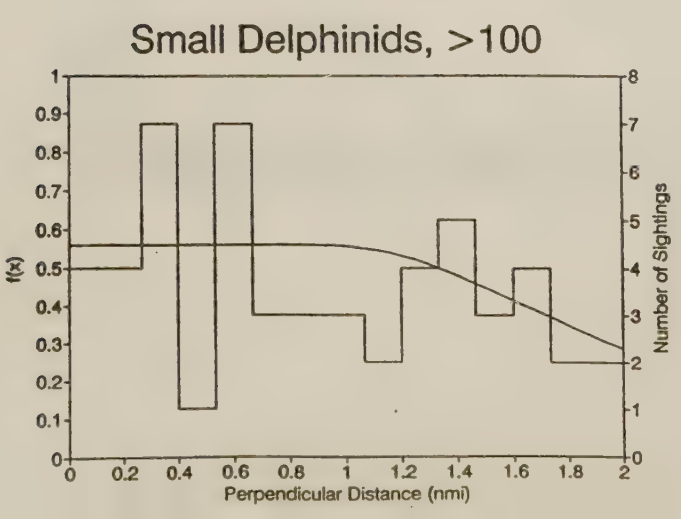
Figure 7. Shapes of the estimated probability density functions (f(x)) and histograms of the observed number of sightings for each of the species groups used to estimate abundance. Truncation distances are 3.0 nmi for large whales and 2.0 nmi for all other species groups.

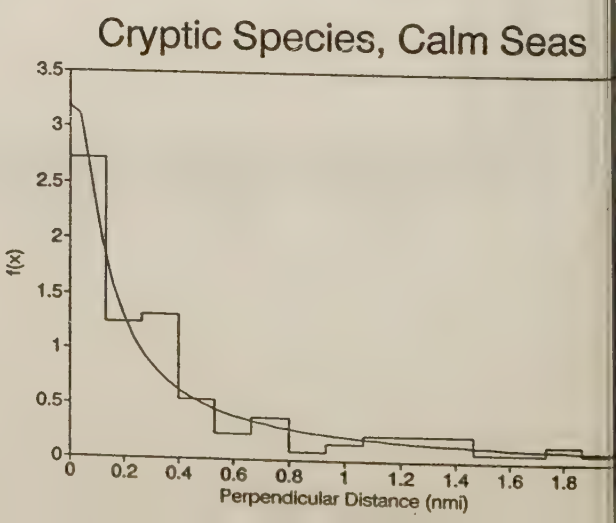




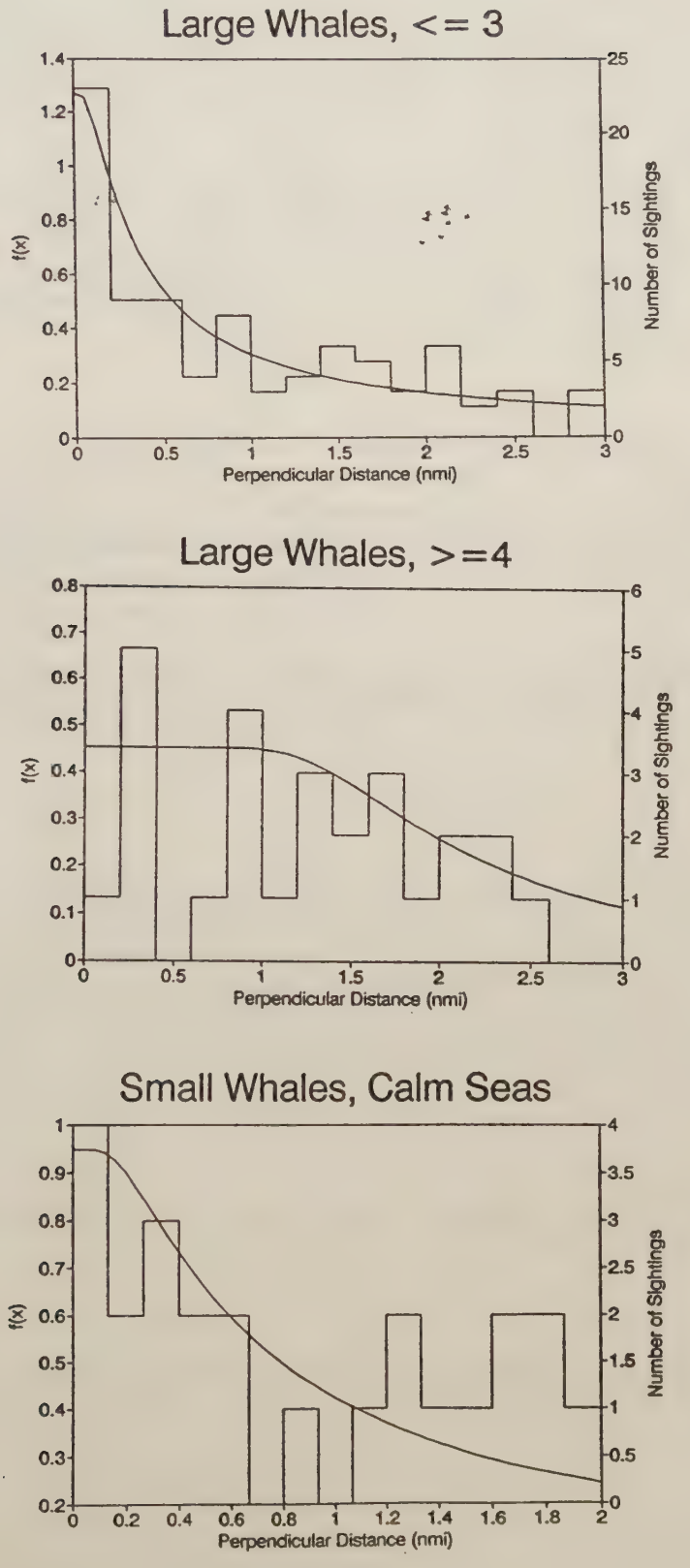








igure 7. (continued).



APPENDIX

To estimate the total fraction of trackline groups missed due to perception bias requires that the survey be designed with two teams of completely independent observers. To be independent, both teams would have to search simultaneously, not notifying or cueing each other until a group of animals had passed abeam of the vessel and were clearly missed by the other team. This approach was deemed infeasible because of the need to approach groups to estimate group size and species composition. If the vessel was not turned until after all groups had passed abeam, a very large percentage of those groups would not be relocated. The probability of relocation would depend on group size and species composition. These factors would add considerably to the difficulty in interpreting these survey data.

Instead, the survey was designed to use a single, conditionally-independent observer who was aware of sightings made by the primary team, but who did not reveal the presence of a group until that group was clearly missed by the primary team. Data from the conditionally-independent observer are used to make an estimate of the probability that the primary survey team detected a trackline group.

The expected number of groups, n, seen very close to the transect line, say within distance δ, can be estimated as

$$n_\delta = \frac{n_\omega \int_0^\delta g(x)\ h(x)\,dx}{\int_0^\omega g(x)\ h(x)\,dx} \qquad (3),$$

where n_w is the total number of groups seen within the truncation distance w, g(x) is the probability of seeing a group that is at perpendicular distance x, and h(x) is the probability that a group will be at perpendicular distance x (usually assumed to be 1.0 for primary observers at all x). As δ approaches zero distance, the above equation can be reexpressed as

$$n_\delta = \frac{n_\omega\ g(0)\ h(0)\ \delta}{\int_0^\omega g(x)\ h(x)\ dx} \qquad (4),$$

which, from the line-transect definition of f(0) (Burnham et al. 1980), can be simplified to

$$n_\delta = n_\omega\ f(0)\ \delta \qquad (5).$$

The probability of a trackline group being seen by the primary observers can be expressed as

$$g_1(0) = \frac{n_{1\delta}}{n_{1\delta} + n_{2\delta}/g_2(0)} \qquad (6),$$

where the subscript 1 refers to sightings made by the primary observers and subscript 2 refers to sightings missed by the primary observers but seen by the independent observer. Combining Equations 5 and 6 and simplifying results in

$$g_1(0) = \frac{n_{1\omega}\, f_1(0)}{n_{1\omega}\, f_1(0) + n_{2\omega}\, f_2(0)/g_2(0)} \qquad (7).$$

Because there were 3 primary observers, $g_1(0)$ should be greater than or equal to $g_2(0)$. Thus

$$g_1(0) \leq 1 - \frac{n_{2\omega} f_2(0)}{n_{1\omega} f_1(0)} \qquad (8).$$

This equation was applied (substituting = for $\leq$) to the subset of data collected while an independent observer was on duty to estimate the probability that a group on the trackline would have been seen by the primary observer team.

The coefficient of variation for $g_1(0)$ can be approximated as

$$C.V.(g_1(0)) = \frac{m\ C.V.(m)}{1 - m} \qquad (9)$$

given

$$m = \frac{n_{2\omega} f_2(0)}{n_{1\omega} f_1(0)} \qquad (10)$$

and

$$C.V.(m)) = \sqrt{C.V.^2(n_{1\omega}) + C.V.^2(n_{2\omega}) + C.V.^2(f_1(0)) + C.V.^2(f_2(0))} \qquad (11).$$